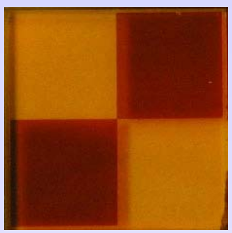
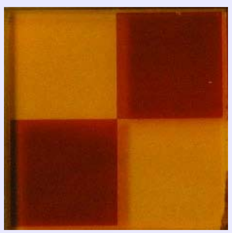
Technical development for Phase-Mask Coronagraphy





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Abstract

Following the original idea by Roddier & Roddier (1997) of a phase-mask coronagraph, Rouan et al. (2000) have proposed a Four-Quadrant phase mask design to solve out the problem of the geometric chromatism.

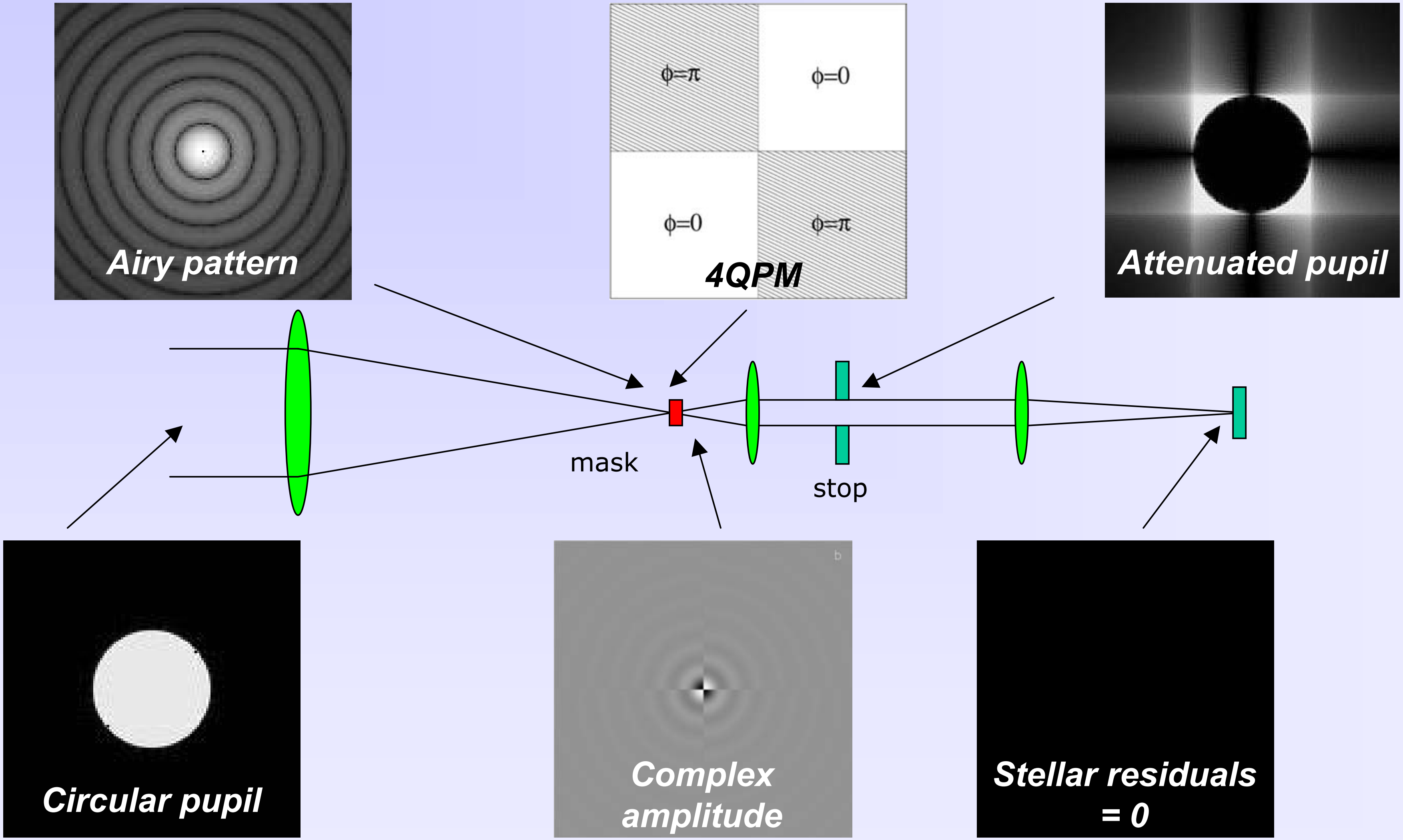
The principle and theoretical performance of the Four-Quadrant Phase-Mask (FQPM) was investigated in several papers (Riaud et al. 2001, Boccaletti et al. 2002, Riaud et al. 2003).

Meanwhile, technological developments were initiated at the Observatoire de Paris-Meudon to prove the concept and to investigate the actual performance in the lab as well as on the sky.

This poster summarizes the lab results in the visible and mid-IR (in the context of JWST) and the very recent observations obtained at the VLT.

The FQPM might be a simple and efficient coronagraphic solution for a TPF coronagraph

Principle of a FQPM



Activities

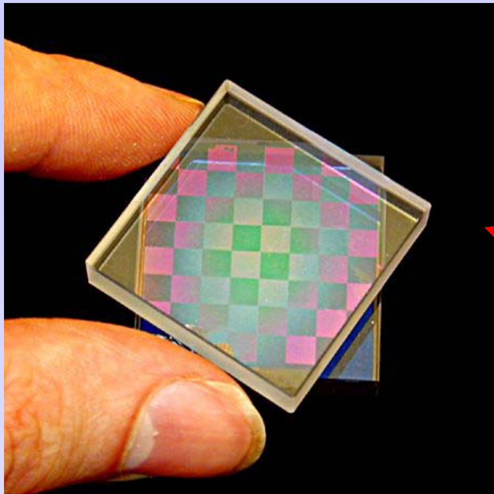
Our group in Observatoire de Meudon is currently involved on 3 projects:

1. the coronagraphic device of MIRI the mid-IR instrument of JWST. 3 phase masks and 1 Lyot mask each optimized for a specific wavelength will be installed at the focal plane of MIRI. The Phase B has started on May 2003 and we have the responsibility to manufacture and address the performance of the 4 coronagraphs. Simulations indicate that giant planets with a temperature of about 300K are potentially detectable at 5AU from a G2V located 10pc.

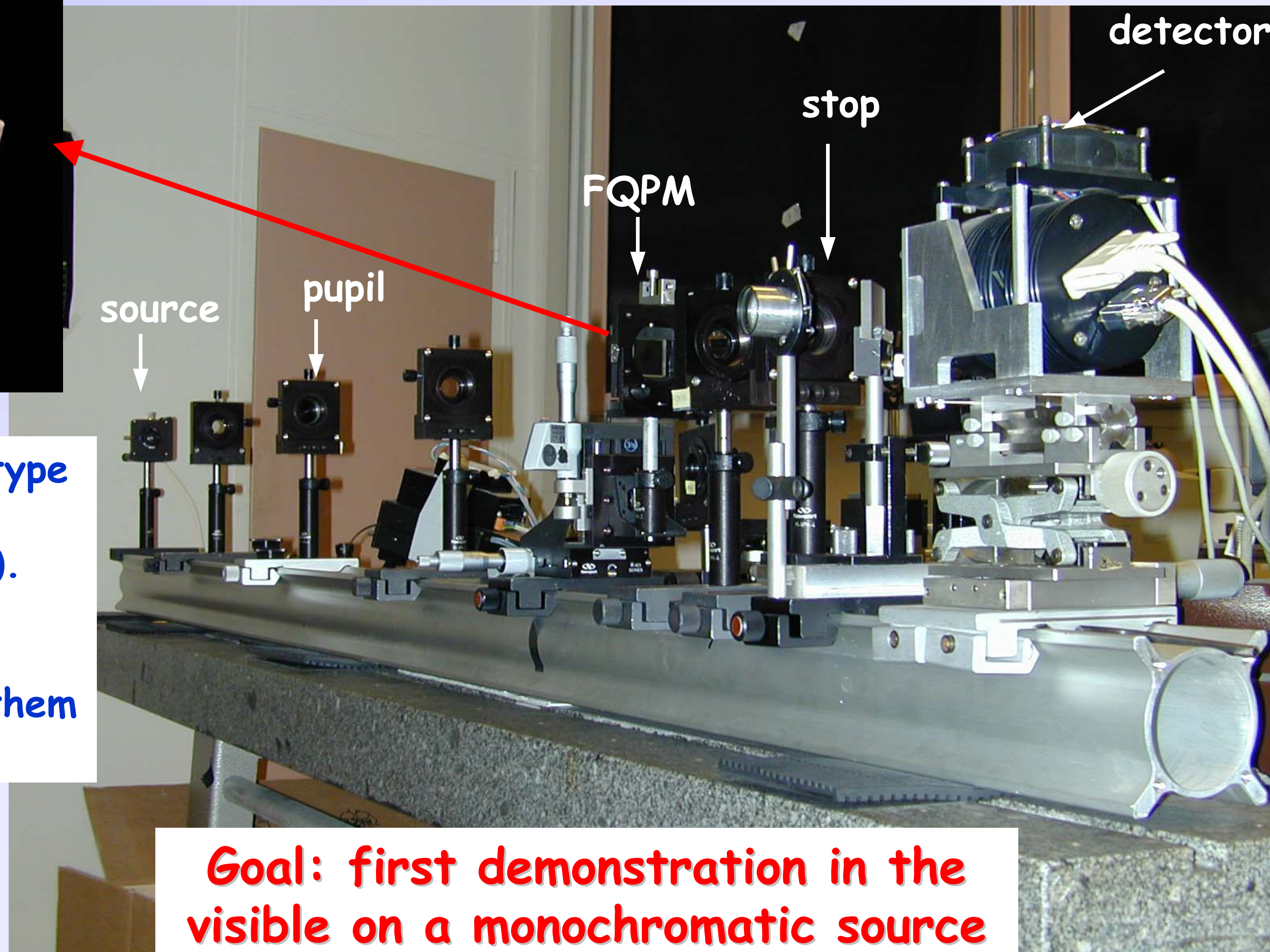
2. the Planet Finder, a 2nd generation instrument for the VLT (ESO-Chile). In this context we are developing intensive simulations to assess the best instrumental concept. Our strategy is to combine advanced coronagraphic technique (phase mask, apodized Lyot, AIC) with differential imaging.

3. a phase mask coronagraph was implemented on NACO the AO system of the VLT and will be commissioned any time soon. This mask will allow to probe the stellar environment down to 50mas therefore representing a significant step with respect to classical Lyot coronagraphy. This device will significantly contribute to the study of stellar environment.

Optical bench in the visible

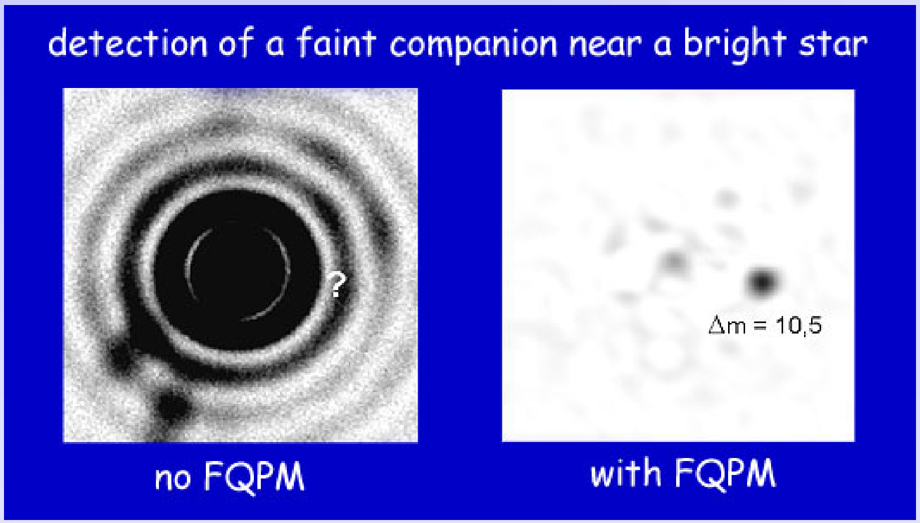


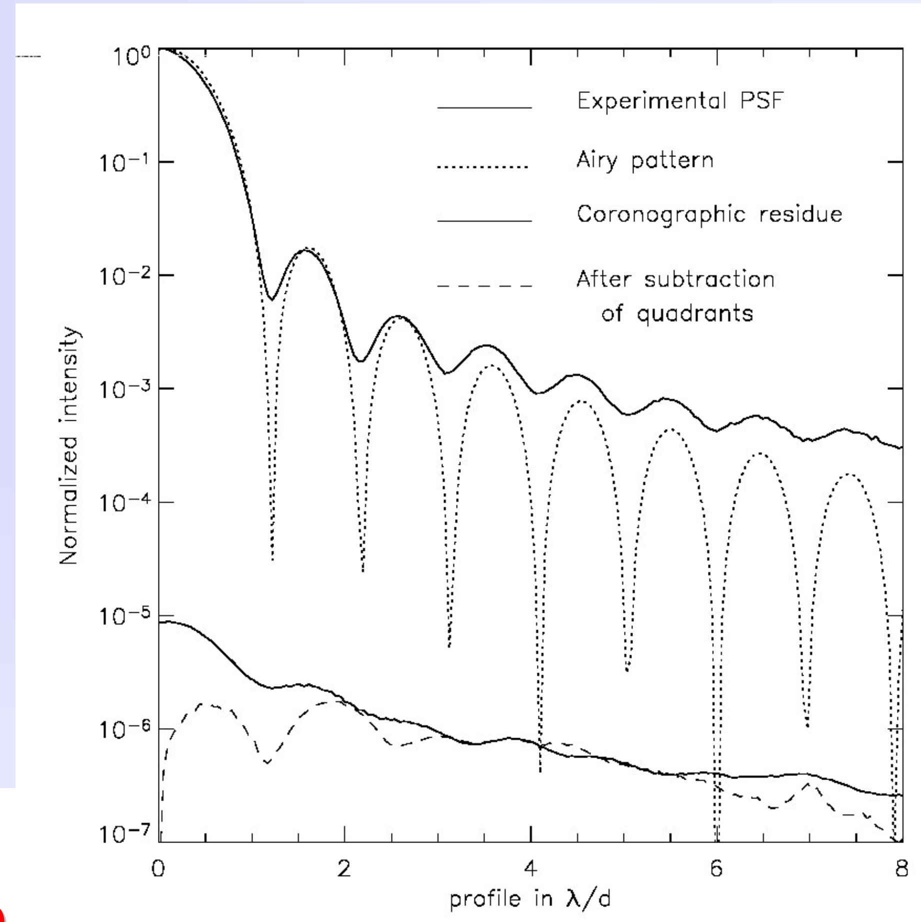
Visible FQPM prototype manufactured by REOSC (λ=0.632μm). The substrate is composed with 8x8 quadrants, half of them being π shifted



Goal: first demonstration in the visible on a monochromatic source

Lab. results in the visible

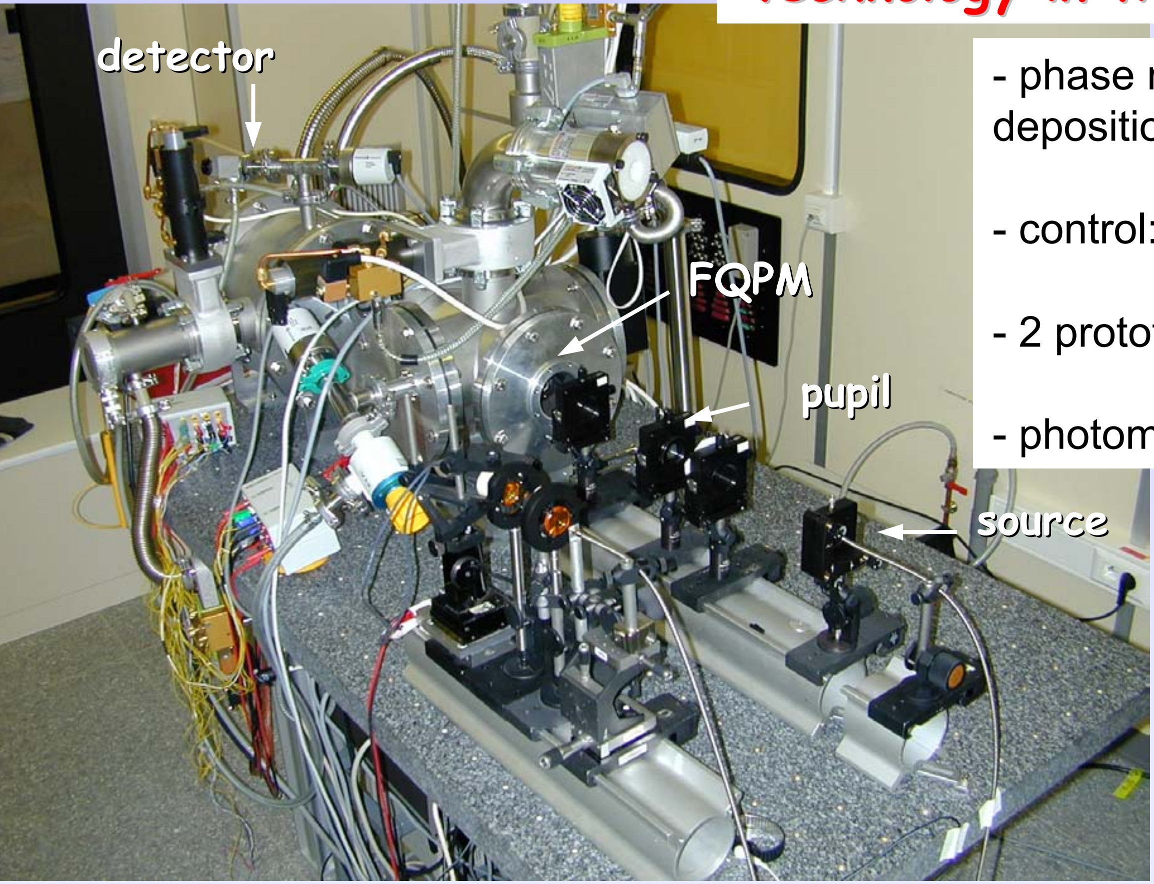




- total rejection factor ≈ 8000
- stellar peak attenuation ≈ 90000
- speckle level ≈ 10^{-6}-10^{-7} (>2λ/D)

Optical bench in the mid-IR

Goal: demonstration of the phase-mask technology in the mid IR for JWST/MIRI



Cryogenic facility

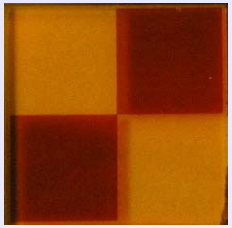
T_{min} =40 K - λ_{max} = 5 μm

- phase masks are manufactured by deposition of ZnSe layer on a ZnSe substrate

- control: metrology and thermal cycling

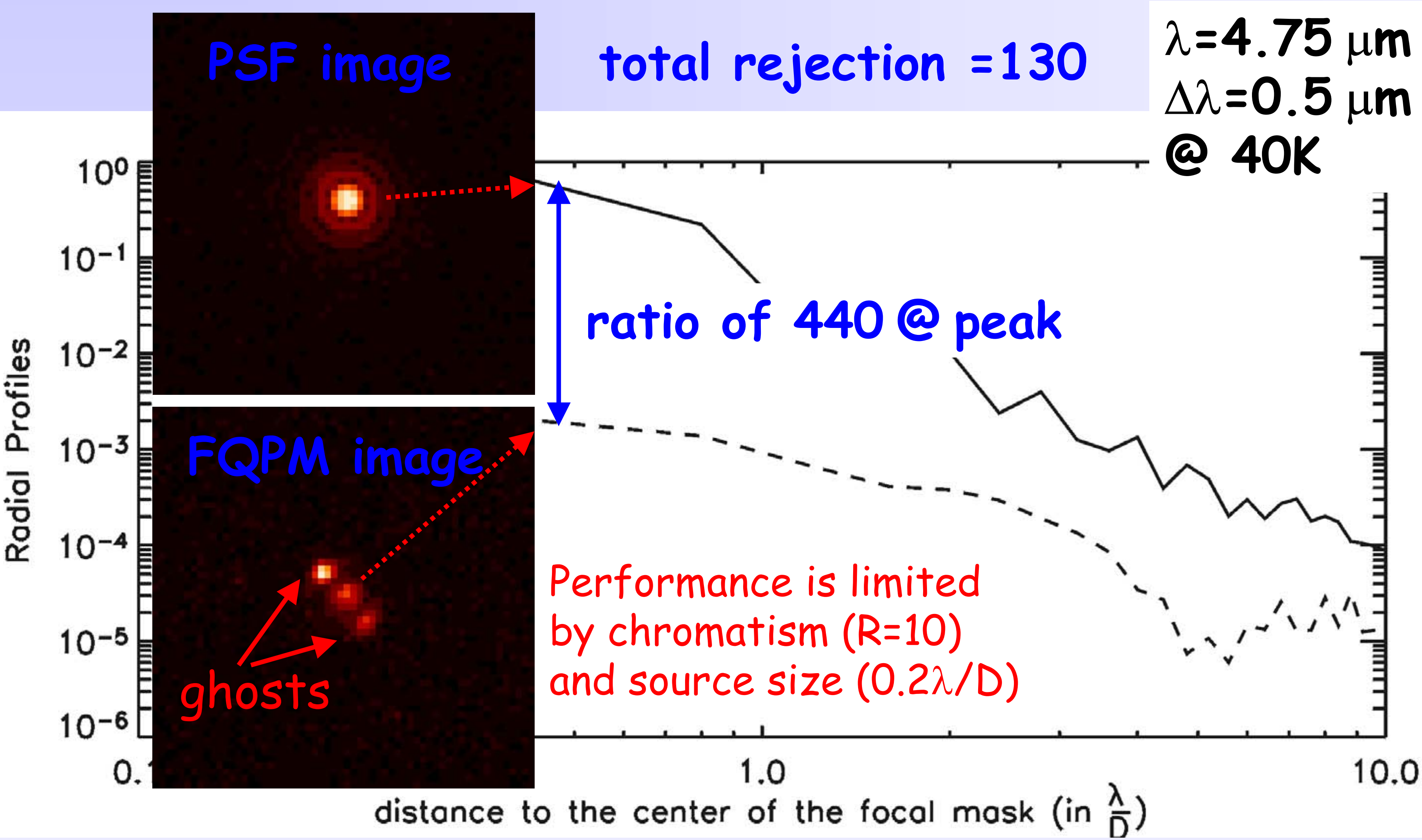
- 2 prototypes : 4.8μm and 16μm

- photometric test in cryogenic conditions



ZnSe component

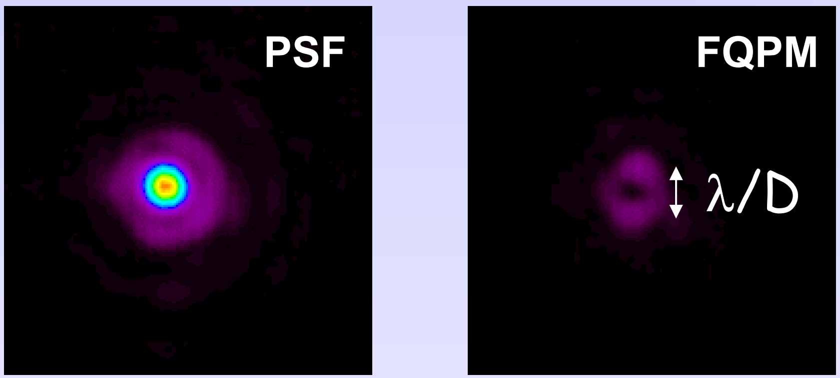
Lab. results in the mid-IR



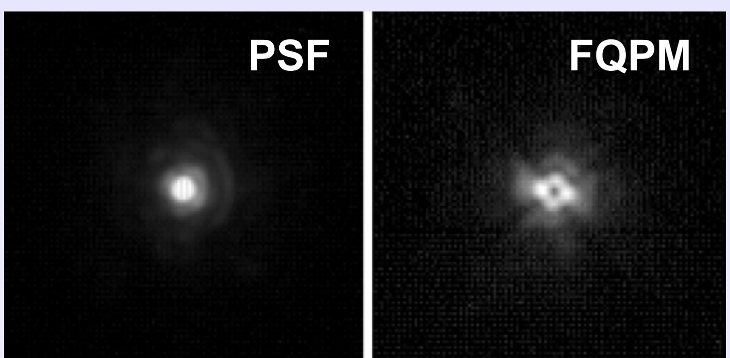
First light at VLT

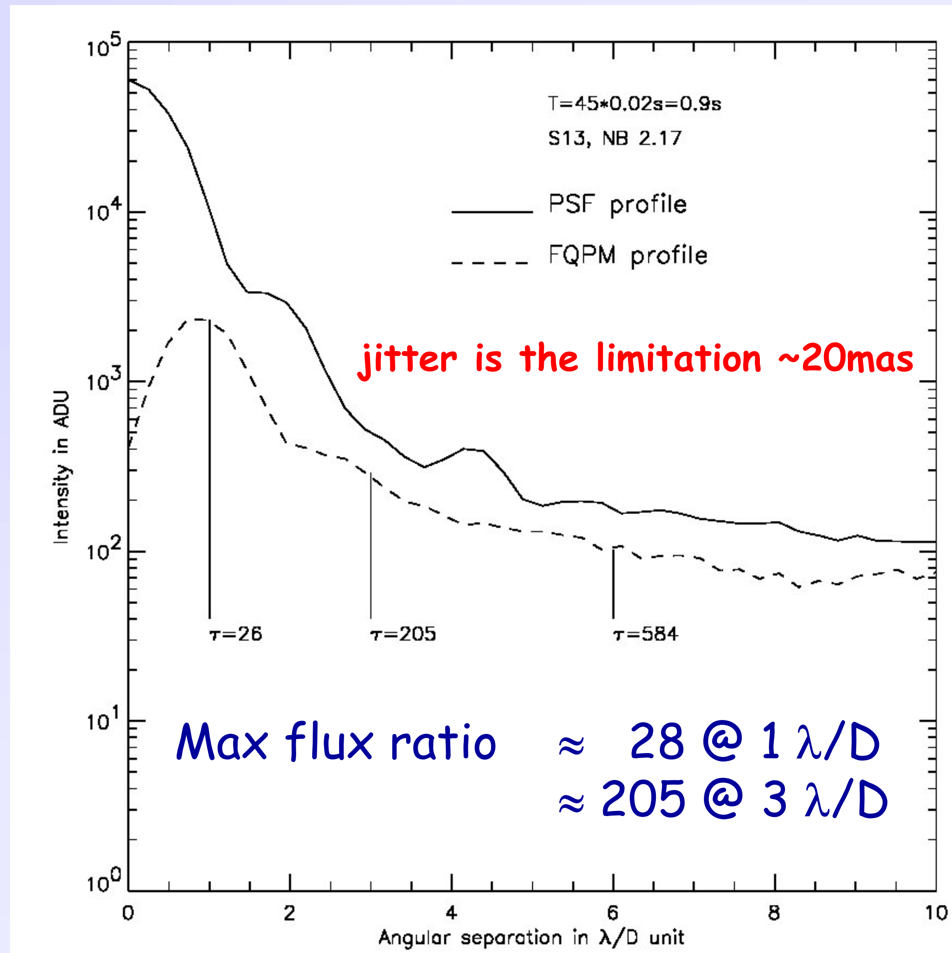
- a FQPM was installed on the VLT (ESO - Chile) on August 2003
- This device is designed to operate in the K band and will be commissioned soon

Narrow band (Brγ, 2.17μm)

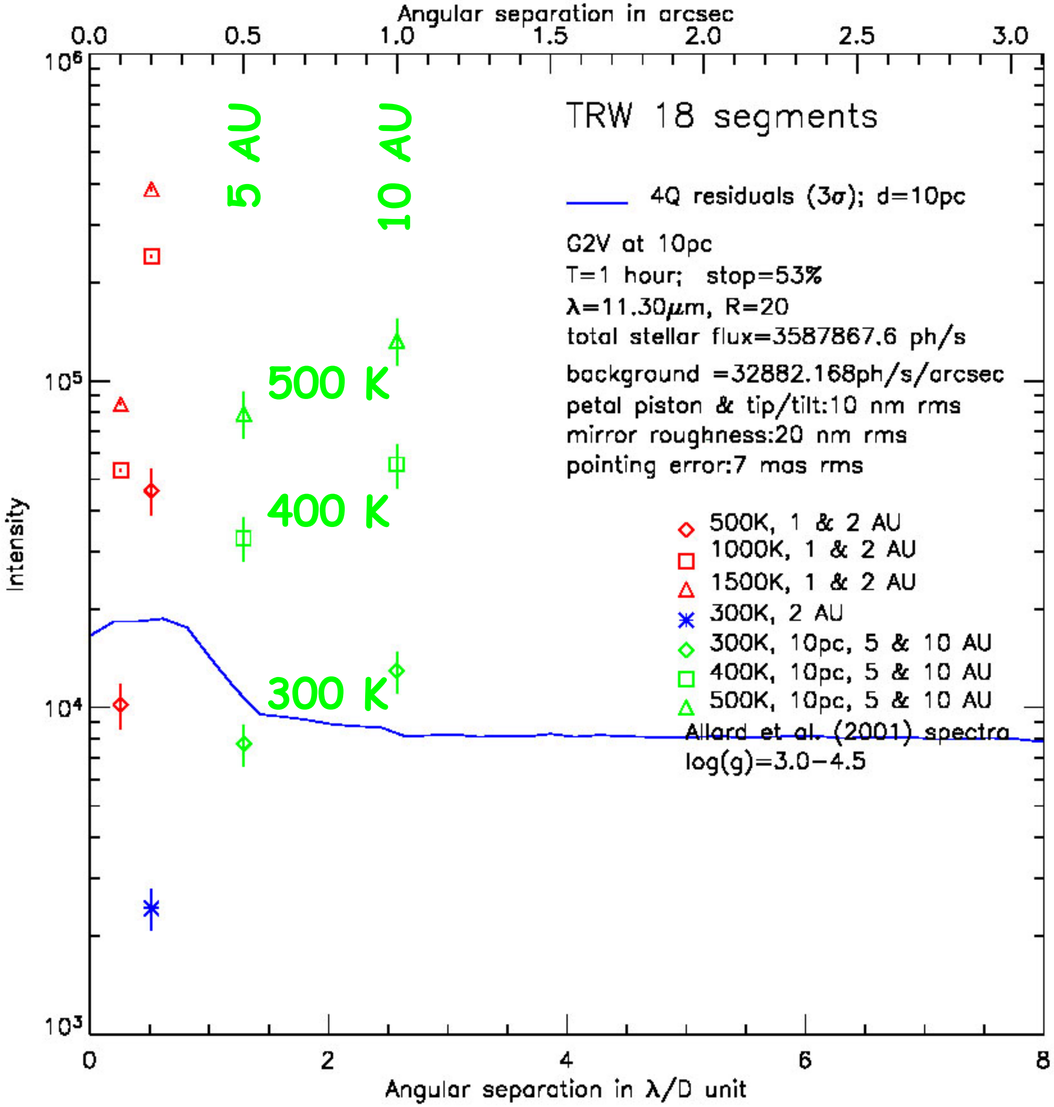


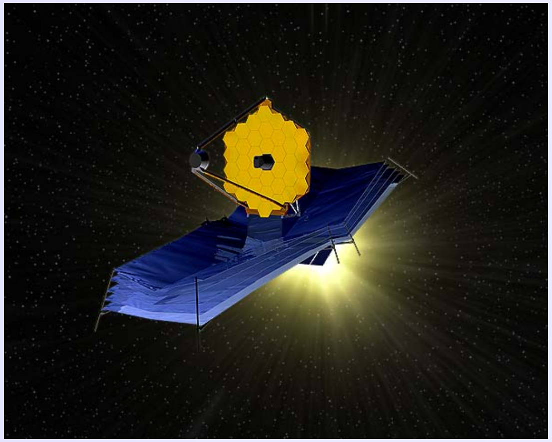
Broad band (Ks, 2.2μm)





Numerical Simulation for JWST-MIRI





Expected detectivity at λ=11.3μm, R=10 with a monochromatic FQPM

The spectral domain between 9 and 12 μm is the best compromise between contrast and background noise.

Chromatism issue

The π phase shift is wavelength dependent :

$\lambda = \lambda_0 \implies \phi=\pi$

$\lambda \neq \lambda_0 \implies \phi=\pi\lambda_0/\lambda$

On the ground as well as for JWST, the achromatization is not required (if $\lambda/\Delta\lambda>20$) since other parameters are contributing to the error budget at a higher level (shape of the pupil and/or atmospheric turbulence).

For more challenging program like TPF, we are studying 2 solutions to make the phase shift achromatic :

1. half-wave plates : - combination of 2 materials Quartz and MgF_2
   - a first prototype is being manufactured and will be tested soon ($\Delta\phi=10^{-1}$ radian)
2. ZOG: - Zero Order Grating studied in collaboration with Université de Liège (Belgium) is the most promising solution ($\Delta\phi=10^{-3}$ radian)

To address for a TPF concept

Some conclusions :

- 10^{-6} contrast still feasible on coronagraphic imaging (@ $2\lambda/D$)
- FQPM doesn't obscurate the focal plane and allow high contrast down to λ/D
- no flux loss if circular pupil
- lessons learnt from JWST/MIRI coronagraphic study
- recently implemented on a ground-based telescope (significant science return is expected)
- manufacturing for visible and near-IR is well known

To be done :

- manufacturing and test of an achromatic component
- carry out numerical simulations to address optimal telescope diameter, wavelength, spectral range & comparison with other concept
- differential imaging concept to achieve high contrast and to relax tolerances on mirror polishing
- other speckle calibration concepts to be studied

References

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